# Global Sea Level Observations
# The University of Hawaii Sea Level Center

**Mark A. Merrifield**
**University of Hawaii Sea Level Center**
**Honolulu, HI**

## PROJECT SUMMARY

The University of Hawaii Sea Level Center (UHSLC) collects, processes, analyzes, and distributes tide gauge data from around the world in support of climate and oceanographic research. The UHSLC focuses on the collection of high frequency measurements, sampled at least every hour, that are available in near-real time usually via geostationary satellites. The center complements the Permanent Service for Mean Sea Level (PSMSL), which is the primary archive for historic monthly-averaged time series of sea level. Data are provided to the UHSLC from ~ 450 stations maintained by 65 international agencies. In addition, the UHSLC directly assists host countries in the maintenance and operation of 50 stations, including 7 stations with colocated GPS for monitoring land motion at the tide gauge. The UHSLC is an active contributor to the Intergovernmental Oceanographic Commission Global Sea Level Observing System (GLOSS), and participates in operational and scientific oversight through the GLOSS Group of Experts. The UHSLC is primarily concerned with the implementation of the Global Climate Observing System (GCOS) sea level network, a subset of GLOSS designated as particularly important for climate research.

The UHSLC distributes near real-time and historic data directly from its host web site, http://uhslc.soest.hawaii.edu, through a dedicated OPeNDAP server, the Pacific Marine Environmental Laboratory Climate Data Portal, the National Ocean Partnership Program (NOPP) sponsored National Virtual Ocean Data System (NVODS) project, and the NOAA Observing Systems Architecture (NOSA) geospatial and geospatial metadata databases. The center also collaborates with NOAA's National Oceanographic Data Center (NODC) to maintain the Joint Archive for Sea Level (JASL), which is a quality assured database of hourly sea level from selected global stations.

UHSLC datasets are used in conjunction with operational numerical models, for the calibration of satellite altimeter data, the production of oceanographic products, and research on interannual to decadal climate fluctuations and short-term extreme events. UHSLC station data are made available directly to the Pacific Tsunami Warning Center and the Japanese Meteorological Agency for tsunami monitoring, as well as to various national tsunami warning agencies. Over the years the UHSLC has participated in national and international programs including NORPAX, TOGA and WOCE, and currently is a designated CLIVAR data assembly center and a GLOSS data archive center.

## ACCOMPLISHMENTS

### Tide Gauge Operations

The UHSLC assists with the operation and maintenance of 48 international tide gauge stations in collaboration with local operators (Figure 1). All of these stations transmit data via the GOES, Meteosat, or GMT satellites. The transmission cycles have historically been between 1 to 3 hours of 2-6 minute averaged data; however, we are in the process of switching all stations over to 15-minute transmissions of 1-minute averages, with even higher rates at major tsunami generation zones. Of the 50 UHSLC stations, 40 contribute to the GLOSS Core network, and 34 to the GCOS network. 7 are equipped with co-located GPS, and 14 are within 10 km of a continuous GPS reference site. The UHSLC shares responsibility for the sites with local operators, which lowers our costs by reducing travel for our technicians while raising the reliability of the stations and the data quality. At most locations, on-site personnel perform regular maintenance, tide staff measurements, and provide security. UHSLC's role has been to provide spare parts as needed, to visit the sites on 1-3 year intervals to ensure the proper operation of the station, to trouble-shoot problems as they arise in coordination with local operators, and to quality assess the datasets.

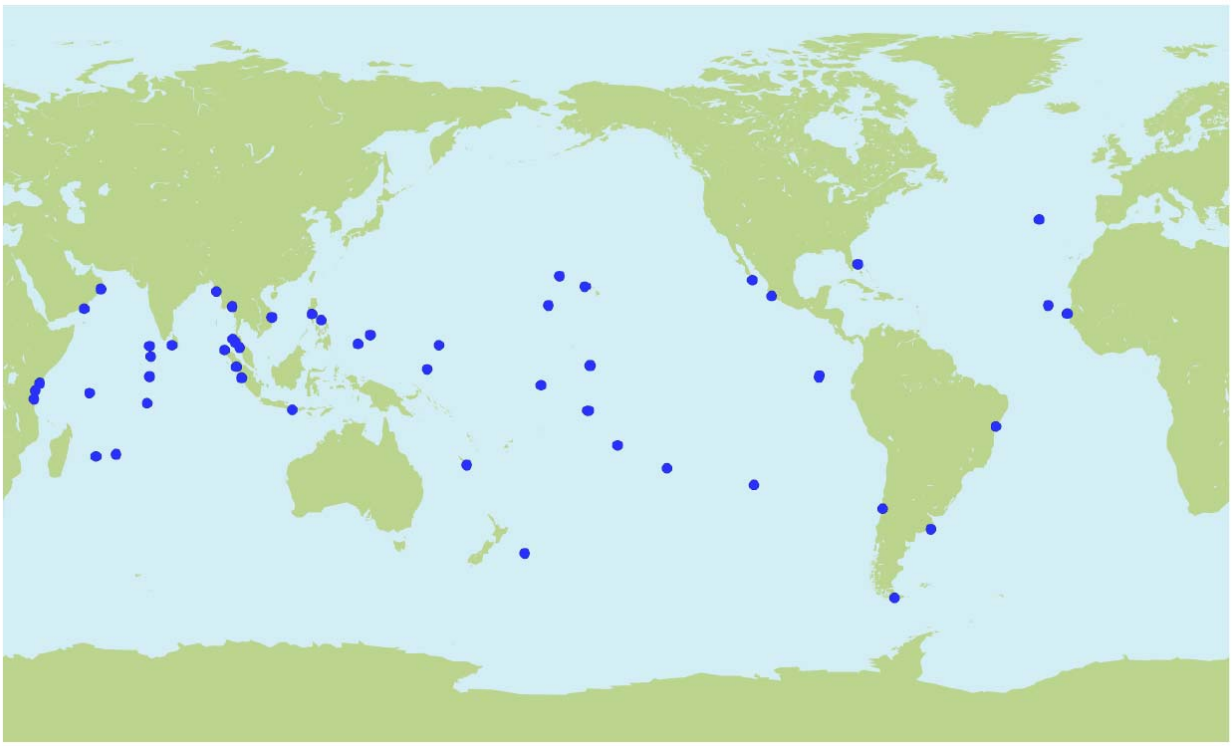

**Figure 1.** Tide gauge stations operated and maintained with assistance from the UHSLC.

New station installations and upgrades of existing OCO stations during October 2005-November 2006 were made primarily in the Indian Ocean in support of the implementation of the Indian Ocean Tsunami Warning System (IOTWS) (Table 1). All but 3 involved substantial financial

support from co-sponsoring agencies (the Intergovernmental Oceanographic Commission, IOC; the Asian Disaster Preparedness Center, ADPC; and USAID). Our ability to accomplish these installations at low costs to the co-sponsors was due to our core operational support provided by OCO. In turn, our involvement in this implementation benefited the aims of the global sea level network and OCO by ensuring that all stations are suitable for sea level monitoring as well as tsunami warning. All are equipped with open-air radar sensors, and most feature a backup float gauge or acoustic sensor, for stable and accurate long-term measurements. All of these sites are either in the GLOSS Core Network or they will be proposed as new additions to the network at the next GLOSS meeting. In addition, we intend to recommend many of these sites as replacements for nearby GCOS stations that have a low probability of becoming operational.

| **Station** | **Country** | **Date of Visit** | **Co-Sponsor** |
|---|---|---|---|
| *Ko Taphao Noi* | Thailand | 2005/10 | ADPC |
| *Ko Meang* | Thailand | 2005/11 | ADPC |
| *Sibolga* | Indonesia | 2005/12 | USAID |
| *Padang* | Indonesia | 2006/02 | IOC |
| *Sabang* | Indonesia | 2006/02 | IOC |
| *Benoa* | Indonesia | 2006/02 | IOC |
| *Manila* | Philippines | 2006/03 | |
| *Legaspi* | Philippines | 2006/04 | |
| Masirah | Oman | 2006/03 | IOC |
| Salalah | Oman | 2006/03 | IOC |
| Male | Maldives | 2006/05 | IOC |
| Gan | Maldives | 2006/05 | USAID |
| Hanimaadhoo | Maldives | 2006/05 | USAID |
| Colombo | Sri Lanka | 2006/05 | USAID |
| Lamu | Kenya | 2006/07 | IOC |
| Zanzibar | Tanzania | 2006/07 | IOC |
| *Langkawi* | Malaysia | 2006/07 | IOC |
| Mombasa | Kenya | 2006/07 | |
| Point Larue | Seychelles | 2006/08 | IOC |
| *Qui Nhon* | Viet Nam | 2006/08 | ADPC |
| Diego Garcia | United Kingdom | 2006/09 | IOC |
| *Sittwe* | Myanmar | 2006/09 | IOC |
| *Moulmein* | Myanmar | 2006/09 | IOC |

## Dataset Holdings

The Joint Archive for Sea Level (data latency: 1-2 years) is a collaborative effort between the National Oceanographic Data Center (NODC), the World Data Center-A for Oceanography, and the UHSLC. A NOAA Liaison officer supported by National Coastal Data Development Center (NCDDC) helps maintain the JASL. The JASL consists of a quality assured database of hourly sea level time series from stations around the world. We consider this to be our research quality database, complementary to the monthly averaged data maintained as PSMSL. In the past year, the UHSLC increased its JASL holdings to 10,651 station-years, including 6,054 station-years at 217 GLOSS sites. Of the 101 GLOSS stations that are presently operating on islands, 98 are available through the JASL. The 2006 submission of the JASL data to the World Data Center-A for Oceanography included 134 series that contained measurements through the year 2005.

The UHSLC maintains a fast delivery database (data latency: 1 month) in support of various national and international programs (e.g., GODAE, CLIVAR, GLOSS, GCOS). To ensure active participation and coordination with the international community, the database has been designated by the IOC as a component of the GLOSS program. The fast delivery data are used extensively by the altimeter community for ongoing assessment and calibration of satellite altimeter datasets. In particular, fast delivery data are used for monitoring the latest JASON altimeter and for the tie between JASON, TOPEX/Poseidon, ERS, and GEOSAT satellites. The fast delivery sea level dataset now includes 181 stations, 142 of which are located at GLOSS sites, and 105 at GCOS sites.

We consider a fully operational network to have near real-time reporting capability. We post the most recent 5 days of data from approximately 180 stations as part of our near-real time website (http://ilikai.soest.hawaii.edu/RSL/). At most of these sites, the data are also available for direct download. Real-time data are received via a number of transmission channels. For example, data from UHSLC operated stations are received at the data center within minutes of transmission using the geostationary meteorological satellite system and the GTS. Data from the U.K. stations are received via email and updated within hours of transmission. NOAA CO-OPS data are obtained via the GTS and a backup download from their web site. Data from Chile and other countries that use the GOES are acquired via the GTS and also downloaded from the GOES web site.

As part of the JCOMM SLP-Pac, the UHSLC operates a Specialized Oceanographic Center that produces sea surface topography maps (monthly) and diagnostic time series (quarterly) for the Pacific Ocean. This activity is a continuation of one of the earliest examples of operational oceanography. The analysis includes comparisons of tide gauge and altimeter sea surface elevations that are available at our web site (http://ilikai.soest.hawaii.edu/uhslc/products.html).

The center produces CD-ROMs that mirror the UHSLC web site. These CDs are distributed with the JASL annual data report, shared with all data originators, and sent to other users upon request. Over 100 were distributed again last year.

## GCOS Network Status

The UHSLC is working with GLOSS and international partners to bring the 180 stations in the GCOS network into full operational mode, which means having all stations report high quality

data in near-real time, with the majority of stations having some sort of vertical datum control via GPS or DORIS. The status of the GCOS network is summarized in Figure 2. In the past year, we've added approximately 35 new GCOS stations into the near-real time data stream, so that 57% of the network is at that capability. An additional 11 stations report within a month as part of the Fast Delivery database. We expect many of these stations to transition to near-real time as upgrades continue, particularly in response to recent tsunami network improvements. 70 of the GCOS stations have nearby GPS or DORIS for datum control. Immediate implementation plans for the GCOS network are described in the FY2007 work plan.

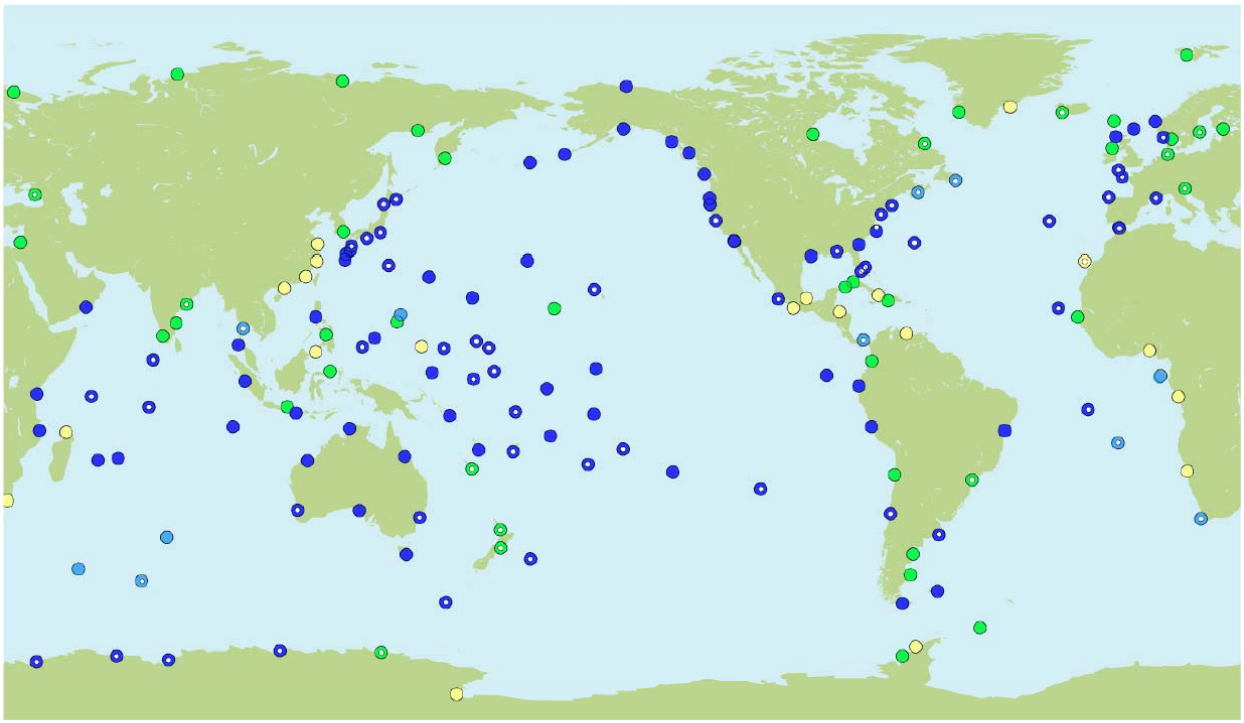

**Figure 2.** Summary of GCOS station data availability at UHSLC as of November 2006. "Data < 2000" indicates that hourly averaged data are not available after 2000. "Data > 2000" indicates that hourly averaged data are available after 2000, but not in Fast or Near Real-Time modes. Stations with nearby GPS/DORIS are indicated with a white dot.

**Research Highlights**

Research during FY06 focused on annual reporting of sea level, extreme events, and sea level rise estimates.

A method for estimating relative sea level rise using a combination of tide gauges, SAR, and GPS measurements was presented using the Southern California coastal region as a case study in a GRL manuscript (Brooks et al., 2006). SAR images are used to estimate vertical ground motion along the entire coastal strip. Tide gauge and GPS information are then incorporated to give a full description of relative sea level variability along the coastline. We are exploring the use of this method for the San Francisco Bay and Seattle/Tacoma metropolitan areas.

A climatology for extreme events is being developed for GLOSS tide gauges. The method produces annual exceedence estimates for extreme water levels, and determines the contribution

to these extremes caused by seasonal heating, tidal variations, and short-term meteorologically-forced events at each site. This work was presented at the WCRP Paris Sea Level Workshop and a manuscript is in preparation.

An estimate of land motion at all of our colocated GPS tide gauge stations was presented at the Jason Science Working Team meeting in Venice, Italy. We are evaluating how reference frame uncertainties affect these estimates. A paper is in preparation describing how land motion corrected trend estimates from these sites compare to recent altimeter estimates.

We took part in the second OCO contribution to the BAMS State of the Climate report, describing sea level patterns during 2005, and an update of global sea level rise estimates (Merrifield et al., 2006).

A summary of sea level rise estimates based on tide gauge and satellite altimeter datasets was presented at the WCRP Paris Sea Level workshop (Merrifield et al., 2006).

**Conferences, Meetings, Expert Panels, and Working Groups**

- December 2005 – Attended the Intersession Working Group for Sea level at the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS), Second Session, Hyderabad, India.
- February 2006 – Presented "ICG/IOTWS-II: Working Group for Sea Level" at the NOAA International Tsunami Project Team Meeting in Seattle, WA.
- March 2006 – Presented "The Global Sea Level Observing System (GLOSS)" at the 6th Meeting of the North Indian Ocean Hydrographic Commission (NIOHC) in Colombia, Sri Lanka
- April 2006 – Attended the IOTWS Regional/National Tsunami Warning Center/Watch Provider CONOPS Workshop, Honolulu, Hawaii
- April 2006 - Met with ADPC in Bangkok concerning the Southeast Asia Tsunami Warning System.
- April 2006 – Attended and presented "The Global Sea Level Observing System (GLOSS)" at the International Round Table Dialogue on Earthquake and Tsunami Risk in Southeast Asia and the South China Sea Region.
- April 2006 – Attended the ICG/IOTWS-II Intersession Working Group for Sea level meeting in Melbourne, Australia.
- May 2006 – Attended the 21st Session of the ICG-PTWS-XXI, Melbourne, Australia.
- June 2006 - Co-chaired the working group on "20th Century Sea Level Change Estimates from Tide Gauges and Altimeters" at the WCRP Sea Level Workshop, Paris, France.
- August 2006 – Attended the ICG/IOTWS Intersession Working Group for Sea level at the ICG/IOTWS Third Session, Bali, Indonesia
- August 2006 - NOAA International Tsunami Project Team Meeting, Seattle

## PUBLICATIONS AND REPORTS

Brooks, B. A., M. Merrifield, J. Foster, C. L. Werner, F. Gomez, M. Bevis, 2006: Space geodetic determination of spatial variability in relative sea level change, Los Angeles basin, accepted *Geophys. Res. Lett.*, 2006.

Caldwell, P. and M. Merrifield, 2006. Joint Archive for Sea Level Annual Data Report: March 2006. JIMAR Contribution No. 06-360, Data Report No. 19, SOEST, University of Hawaii, 41 pp.

Merrifield, M. A., S. Gill, and G. T. Mitchum, 2006: *Sea Level*. In chapter 3 of the "State of the Climate in 2005", K.A. Shein (ed.), *Bulletin of the American Meteorological Society*, **87** (6), S28-S29.

Mitchum, G. T., R. Steven Nerem, and M. A. Merrifield, 2006: 20th Century Sea Level Change Estimates from Tide Gauges and Altimeters, in Understanding Sea Level Rise and Variability, Ed. J. Church, P. Woodworth, T. Aarup, S. Wilson, in preparation.